

# Introduction, History, Types and Application of Lithium ION Battery (A Review)

Ajmal Shariff<sup>1#</sup>, Salman Khan<sup>2#</sup>, Arshad Ahmed<sup>1</sup>, D. M. Srinivasa<sup>1</sup>, Asha M. S<sup>3</sup> and Zabiulla<sup>3\*</sup>

<sup>1</sup>Department of Electrical and Electronics Engineering, PES College of Engineering, Mandya, Karnataka, India.

<sup>2</sup>Department of Electrical and Electronics Engineering, Vidyavardhaka College of Engineering, Mysuru, Karnataka, India.

<sup>3</sup>PG Department of Studies and Research Centre in Chemistry (A recognized research centre of University of Mysore), St. Philomena's College Bannimantap, Mysuru, Karnataka, India.

<sup>3\*</sup>Assistant Professor, PG Department of Studies and Research in Chemistry, St. Philomena's College (Autonomous), Mysore, Karnataka, India

-----  
\*\*\*  
-----

**ABSTRACT:** Lithium-Ion (Li-Ion) Batteries Have Only A Short History In Battery Technology, But The Significant Growth In Sales Of These Batteries Has Permitted Them To Take A Leading Position In The Rechargeable Battery Field. Li-Ion Batteries Are Receiving Huge Attention As Storage Devices In The Renewable Energy And Sustainable Road Transport Fields. However, Low-Cost, Long-Life Lithium Batteries With Higher Energy Densities Are Required To Facilitate Practical Application. This Paper Reviews The Different Types Of Li-Ion Batteries That Are Used In Worldwide For Their Respective Applications. Battery Technology Is One Of The Key Technologies For Developing Electric Drive Vehicles.

Among Many Kinds Of Batteries, Li-Ion Batteries Have Become The Focus Of Research Interest For Applications In Electric Vehicles, Hybrid Electric Vehicles, Portable Electronics Devices Such As Mobile Phones, Laptops, Tablets Etc. This Paper Also Reviews Recent Research and Developments of Graphene Based Li-Ion Batteries Anode and Cathode Material.

**Key Words:** Li-Ion; Graphene; Electric Vehicles; Rechargeable Battery.

## 1. INTRODUCTION.

In The 21<sup>st</sup> Century Energy Shortage Being One Of The Increasing Problems, Research Has Been Developed To Replace The Non-Renewable Fossil Fuels By Other Green Energy Sources, Such As Solar, Tidal, Wind And Hydroelectric Power. Different From The Conventional Fossil Fuels, The Difficulties That Are Been Facing Today With These Green Energy Sources Are Their Uncontrollable And Intermittent Nature, Therefore The Cost Is Increases As It Faces Difficulties In Energy Storage And Regulation. As Energy Shortage And Environmental Problems Emerge As The Great Challenges. This Brings In Enormous Amount Of Research Interests In Material Developments For Energy Storage [1]. The Li- Ion Battery System Is Considered As Unmatchable Combination Of Features Like High Energy Storage, Less Space Required And Power Density, Making It The Technology Of Choice For Portable Electronics Devices (Peds), Power Tools, And Hybrid Electric Vehicles (Hevs)/Electric Vehicles (Evs) [2] And Relatively Simple Reaction Mechanism. Li-Ion Batteries Have Achieved Great Success In Electricity Storage And Supply [3]. Current Li-Ion Battery Technology Is Well Developed For The Peds And Has Been Widely Used In The Past Decade [1]. It Has Seen A Growing Trend Towards Next-Generation Li- Ion Batteries With High Charge Capacities/Power Densities Developed For Evs, Hevs, Aerospace Applications, And Autonomous Electric Devices [4-9]. Li-Ion Battery Technology Is One Of The Key Technologies For Developing Evs. Petrol And Diesel Fuel Vehicles Cause A Large Amount Of Carbon Dioxide Emission, Which Leads To Some Serious Consequences On Global Warming [10]. If Evs Replace The Most Of Gasoline Powered Vehicles, Li-Ion Batteries Will Appreciably Reduce Greenhouse Gas Emissions [11]. Li-Ion Batteries Continue To Draw Huge Attention As A Capable Energy Storage Technology Due To Their High Energy Density, Low Self-Discharge Property, Nearly Zero-Memory Effect, High Open Circuit Voltage, And Extensive Lifespan. In The Automotive Industry, Li-Ion Batteries Are Considered As The Ideal Power Source For Evs And Hevs [12]. The Main Challenges Are Achieving High Reversible Capacity, Stable Cycle Performance And Excellent Rate Capability For Suitable Electrode Materials [13-16].

## 2. HISTORY OF LI-ION BATTERY.

In The 1970's, Whittingham Was One Of The First To Realize The Potential For Lithium, And Elemental Metal That Has Once Loose Electron In Its Outermost Atomic Cell And Easily Gives It Up But That Also Makes Lithium Highly Reactive It Will Ignite And Sometimes Explode When Exposed Even To Water In The Air. Working At Exxon, Whittingham Discovered That

Titanium Disulfide Would Work Well As A Cathode, Li- Ions Could Embed Themselves Within Its Layered Structure. In 1976, Whittingham Demonstrated A Working 2.5-Volt Battery. But As It Went Through Multiple Charging Cycle Whiskery Tendrils, Or Dendrites, Of Lithium Grew Across The Electrolyte. When They Reach The Cathode The Battery Short Circuited And Sometime Causing Fires. Goodenough Then At The University Of Oxford In The United Kingdom, Took Up The Task. He Realized The Cathode Could Soak Up More Returning Electrons If It Was Made Of Metal Oxide Instead Of Metal Sulfide. These Compounds Are Also Layered And Did Not Significantly Expand Or Contract When Taking Up Or Realizing Li- Ions. He Found That Cobalt Oxide Worked Well, And In 1980, Published Result For A 4-Volt Battery, Nearly Twice As Powerful As Whittingham's.

Researchers In Japan Were On The Lookout For Batteries That Could Power Shrinking Wireless Devices (Sony's Walkman Debuted In 1979). Yoshino Made A Huge Contribution, He Found A Way

To Create An Anode That Was Not Made Up Of Pure Lithium, With Its Susceptibility To Growing Dendrites. After Trying Different Materials, He Found That He Could Embed The Li-Ions Within Layers Of Carbon In Petroleum Coke, An Oil Industry Bio Product. Yashino's Battery Matched the Performance of Goodenough's But Was Far Safer, And It Could Survive Hundreds of Charging Cycles. In 1991, A Japanese Company Began To Sell The First Commercial Li-Ion Batteries.

The Two Fundamental Parameters Of Battery Performance Are (1) Energy Density That Indicates How Much Energy A Battery Can Store And (2) Power Density That Indicates Its Maximum Output. **Figure 1** Shows A Historical Outline Of The Improvement Achieved In The Energy Density Of Typical Secondary Batteries For Use In Electric Appliances. In 1990s, Nickel-Cadmium And Lead-Acid Batteries Were Representative Examples Of Secondary Batteries. The Energy Density Of Nickel- Cadmium Batteries Did Not Exceed Approximately  $50 \text{ Whkg}^{-1}$  At The Most. In The Early 1990s, Nickel- Metal Hydride Batteries And Li-Ion Batteries Appeared In Succession, And The Energy Density Of Small Batteries For Consumer Electronics Products Has Been Improved By Nearly Fourfold In Roughly The Last 15 Years [17].

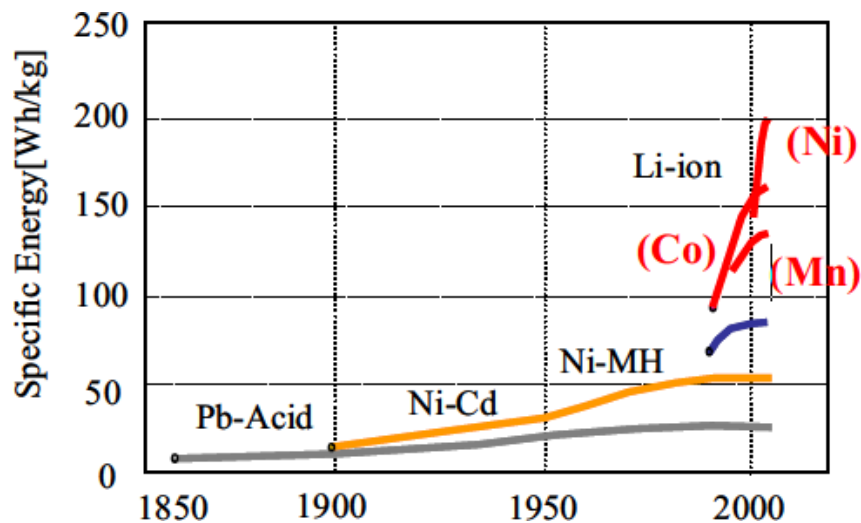


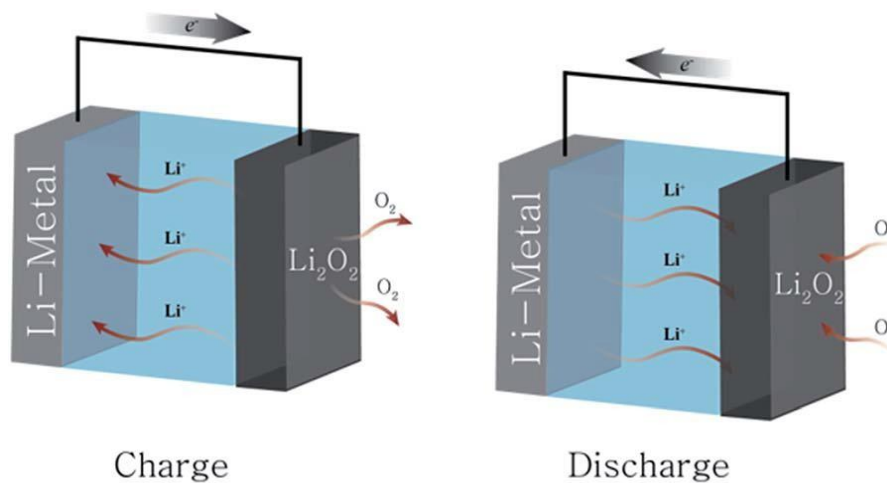
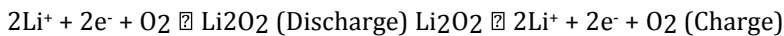
Figure 1: Specific Energy of Secondary Batteries for Electric Appliances

### 3. TYPES OF LI-ION BATTERIES:

#### 3.1. Lithium–Air (Li-Air) Batteries.

Lithium–Air Battery (Li-O<sub>2</sub>) Was Established By Abraham *Et Al*, In 1996 by Using an Organic Electrolyte [18]. The Anode Is Of Li Metal, Whereas The Cathode Is A Carbon Matrix With A Catalyst. The Working Of Li–O<sub>2</sub> Battery Can Be Explained By The Redox Reactions Between Li Metal And Oxygen. Li–O<sub>2</sub> Batteries Have Drawn Much Concentration, As An Alternative Technology To High- Capacity Li-Ion Batteries [19-22]. Its Energy Density Can Reach Upto 1700 Whkg<sup>-1</sup> By Practically [21]. **Figure 2** Shows a Schematic Cell Configuration for the Li–O<sub>2</sub> Batteries with The Following

Reactions.



**Figure 2:** Schematic Cell Configuration for the Li–O<sub>2</sub> Batteries

Li–O<sub>2</sub> Batteries Are Available With Lower Cost As Compared With The Conventional Li-Ion Batteries As It Has Simplicity In The Active Material Composite. The Li–O<sub>2</sub> Battery Can Be Operated Both With Aqueous And Non-Aqueous Electrolytes. Under Aqueous Conditions, During The Discharge, The Air Cathode Is Being Prevented From The Clogging And Also It Is Protected From Being Affected By Over-Potentials Due To The Formation Of LiOH. On The Other Hand, the LiOH Cannot Be Fully

Decomposed On Charge And Thereby It Will Precipitate, Leading To Lower Energy Density And Poor Cyclability [19, 23].

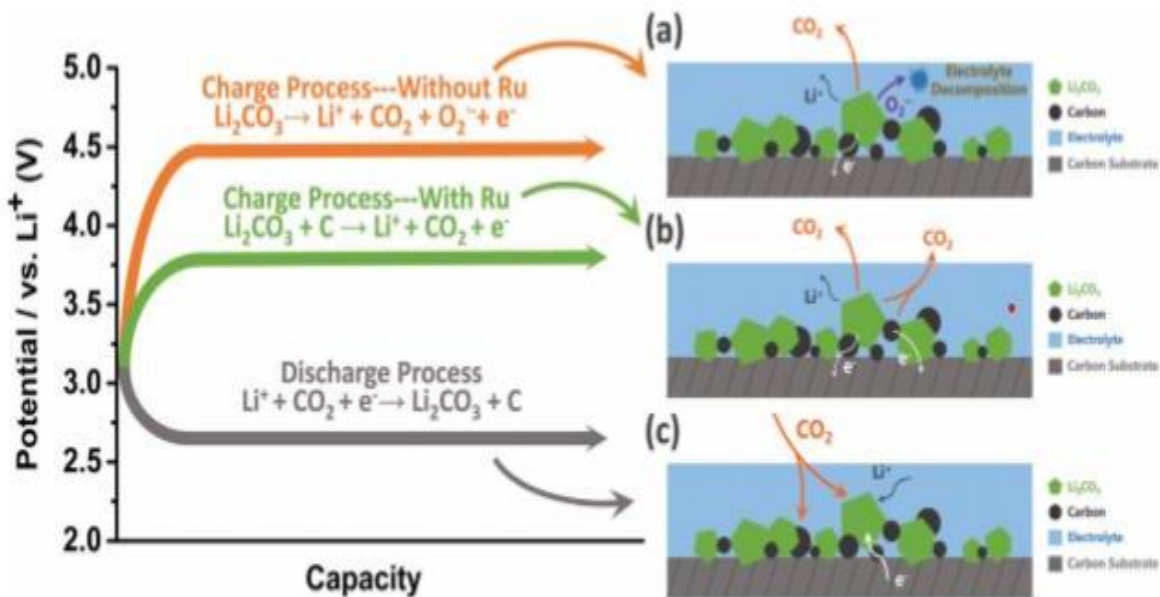
#### 3.2. Lithium –Carbon Dioxide (Li-CO<sub>2</sub>) Batteries.

Recently, The Battery Community Has Revealed An Interest In Li–CO<sub>2</sub> Batteries. The Research By Takechi *Et Al*, Exposed A Novel Battery Employing Gases, Namely, Li/CO<sub>2</sub>–O<sub>2</sub> Exhibited A High Irreversible Discharge Capacity, Which Is Three Times As Compared To The Capacity Of A Li–Air Battery [24]. Later On, The Development Of A Reversible Li/CO<sub>2</sub>–O<sub>2</sub> Battery Using Dimethyl Sulfoxide (DMSO) By Lim And Kang *Et Al*, Which Leads To The Reversible Formation Of Li<sub>2</sub>CO<sub>3</sub> [25]. Xu And Archer *Et Al*, Have Developed A Li–CO<sub>2</sub> Battery That Uses Pure CO<sub>2</sub> Gas As The Working Electrode For Achieving Charge Capacities. A Year Later, Liu *Et Al*, Demonstrated A Pure And Reversible Li/CO<sub>2</sub> Battery Using LiCF<sub>3</sub>SO<sub>3</sub> In TEGDME (1 : 4 In Mole) As The Electrolyte [26] The Charge Capacity Of The Li–CO<sub>2</sub> Can Be Achieved By The Following Electrochemical Reaction [26,27].



Li<sub>2</sub>CO<sub>3</sub> Is The Key Component That Determines The Reversibility Of This Battery Application. However, Li<sub>2</sub>CO<sub>3</sub> Is An Insulator And Thus Requires A High Over-Potential To Be Oxidized On Charge [28]. Recently Zhou's Group Have Used Ruthenium (Ru)

As A Cathode Catalyst To Successfully Reduce The High Over-Potential, Thereby Improving The Reversibility Of The Li-CO<sub>2</sub> Battery (**Figure 3**) [27, 29] Li/CO<sub>2</sub> Battery Is Undeniably An Attractive Technology As It Can Concurrently Deal With Energy And Environmental Issues. However, The Major Problems Such As High Over-Potential And Low Coulombic Efficiency Are To Be Solved For Practical Use.



**Figure 3:** Schematics Of The (A) Reaction Mechanism Of A Li-CO<sub>2</sub> Battery On Charge Without A Ru Catalyst, (B) Reaction Mechanism Of The Li-CO<sub>2</sub> Battery On Charge With A Ru Catalyst, And (C) Discharging Process.

### 3.3. Lithium-Cobalt Oxide (Li-Coo<sub>2</sub>) Batteries.

Flame Aerosol Technology, Especially Flame-Spray Pyrolysis (FSP) Is Thought To Be An Effective Technique For The Creation Of New And Sophisticated Materials For Catalysis, Sensors, Photoluminescence, Biomaterials And Batteries [30-35]. Hadi Mohammadi *Et Al*, Have Demonstrated Cobalt-Oxide (Coo<sub>2</sub>) As Cathode Active Material For Li-Ion Battery. They Developed A Facile, Ultrafast And Green Flame Spray Pyrolysis Method To Efficiently Fabricate Submicron-Sized Lithium Cobaltite Spheres From An Aqueous Spray Solution Of Lithium And Cobalt Nitrates. Molar Ratios Of Lithium: Cobalt Have Altered At Three Different Levels In The Precursor Solution Viz., 1: 1, 1.3: 1 and 1.7: 1. Sample Obtained With Molar Ratio Of Lithium: Cobalt 1.7: 1, Under Different Conditions

Atmosphere Was Calcined. The Sample Calcined In Oxygen Atmosphere With Low Flow Was Phase Pure Crystalline Rhombohedral Lithium Cobalt Oxide. Moreover, The Sample Showed Good Enough Performance As Cathode Active Material Of Li-Ion Battery. At 0.1C The Rechargeable Capacity Was 162 Mah G<sup>-1</sup> And 101 Mahg<sup>-1</sup> At 1 C And Capacity Retention Of 84% After 50 Cycles And The Sample Have Observed At This Rate [36].

Huanlei Wang *Et Al*, Synthesized Co<sub>3</sub>O<sub>4</sub>-Carbon Nanosheet Hybrid Nanoarchitectures By A Facile And Scalable Chemical Process In Order To Improve The Electrochemical Performance Of Cobalt Oxide Due To Its Inherent Poor Electrical Conductivity And Large Volume Expansion/Contraction. Herein, By The Control Of Calcination Condition They Created Nanosized Cobalt Oxide Anchored 3D Arrays of Carbon Nanosheets. The Regularly Dispersed Co<sub>3</sub>O<sub>4</sub> Nanocrystals On Carbon Nanosheets Held A Diameter Down To 5 Nm. When It Is Tested As Anode Materials For Li-Ion Batteries, High Lithium Storage Over 1200 Mahg<sup>-1</sup> Is Achieved, Whereas High Rate Capability With Capacity Of About 390 Mahg<sup>-1</sup> At 10 Ag<sup>-1</sup> Is Maintained



Through Nano Scale Diffusion Distances And Interconnected Porous Structure. After 500 Cycles, The Cobalt Oxide-Carbon Nanosheets Hybrid Display A Reversible Capacity Of About  $970 \text{ Mahg}^{-1}$  At  $1 \text{ Ag}^{-1}$ . This Improves The Specific Capacity And The Initial Coulombic Efficiency Of The Hybrids [37]. However, the Depletion and High Cost of Cobalt Resources Severely Restrict Practical Applications of  $\text{LiCoO}_2$  Materials [38]

### 3.4. Lithium-Manganese Oxide (Li-MnO<sub>2</sub>) Batteries.

During The Past Twenty Years A Number of Families of Transition Metal Oxides As Well As Transition Metal Polyanionic Frameworks Have Been Projected [39, 40]. In Which Manganese Oxides, Such As The  $\text{LiMn}_2\text{O}_4$  Spinel Or The Overlithiated Oxide  $\text{Li}[\text{Li}_{1/3}\text{Mn}_{2/3}]\text{O}_2$ , Have Been Widely Studied Due To The Low Toxicity Of Manganese-Based Materials And The High Redox Potential Of The  $\text{Mn}^{3+}/\text{Mn}^{4+}$  Couple. Rechargeable Magnesium Battery (Rmb) Has Got Increased Attention as It Is One of the Alternative to Current Li-Ion Technology. Magnesium Is the Eighth Abundant Elements in the Earth's Crust with Worldwide Availability and Much Less Cost Risk. Metal Magnesium Anode Has Nearly Doubled Volumetric Capacity ( $3,833 \text{ Mahcc}^{-1}$ ) Of Lithium ( $2,046 \text{ Mahcc}^{-1}$ ). Due To The Lack Of Proper Cathode That Provides High-Energy Density And Good Sustainability Very Hinders The Development Of Practical Rmbs. So Far, The Successful  $\text{Mg}^{2+}$ -Intercalation Was Only Achieved In Only A Few Cathode Hosts, One Of Which Is Manganese Dioxide. Recently the Cathodic Performance of  $\text{MnO}_2$  Was Impressively Improved To the Capacity of  $>150\text{--}200 \text{ Mahg}^{-1}$  at Voltage of  $2.6\text{--}2.8 \text{ V}$  with Cyclability to Hundreds or More Cycles [41].

### 3.5. Lithium-Iron Phosphate (LiFePO<sub>4</sub>) Batteries.

Lithium Iron Phosphate Are Being Extensively Used For Positive Electrodes Of Li-Ion Batteries. The Main Disadvantage Of  $\text{LiFePO}_4$  That Is Its Low Electronic Conductivity Which Was Eliminated By A.A. Chekannikov *Et Al.*, Through The Synthesis Of The Lithium Iron Phosphate Composite With Carbon ( $\text{LiFePO}_4/\text{C}$ ). For The Synthesis Of Lithium Iron Phosphate Samples Doped With Trivalent Cations Of Nickel And Chromium ( $\text{Li}_{0.99}\text{Fe}_{0.98}(\text{CrNi})_{0.01}\text{PO}_4/\text{C}$ ) With The Structure Of Olivine,  $\text{Li}_2\text{CO}_3$ ,  $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ,  $(\text{NH}_4)_2\text{HPO}_4$ ,  $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$   $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  Were Used. Sol-

Gel Method Has Been Employed To Carry Out The Synthesis [43]. In Accordance To The Acquired Data, With The Structure Of Olivine, All The Obtained Samples Of Lithium Iron Phosphate Are Crystallized In The Orthorhombic Modification Of Lithium Iron Phosphate. The Obtained Material's Average Particle Size Varies in the Range Of  $50\text{--}100 \text{ nm}$ . The Carbon Content Was  $4 \text{ wt}\%$ . The Doping Of Lithium Iron Phosphate With Trivalent Cations Of Chromium And Nickel Results In The Increase Of The Discharge Capacity At High Discharge Rates With The Simultaneous Stability Augmentation During The Cycling. Finally It Has Enhanced Electronic Conductivity Of The Material And Reduced Size Of Particles In The Developed Material [43]. Further In Order To Develop a Battery with Increased Power Specifications

A New Electrochemical System Has Been Developed By A.A. Chekannikov *Et Al.*, Where Cathode Material Based On Lithium Iron Phosphate Doped With Nickel And Yttrium ( $\text{Li}_{0.99}\text{Fe}_{0.98}\text{Y}_{0.01}\text{Ni}_{0.01}\text{PO}_4$ ) And Anode Material Based On Doped Lithium Titanate ( $\text{Li}_{3.812}\text{Ti}_{4.972}\text{Ga}_{0.1012}$ ). The Battery Is Made To Use In Fixed Energy Storage Units. The Battery Ability Was Enhanced To Operate At Increased Charging/Discharging Currents (Up To  $30 \text{ C}$ ). The Specific Power Of The Battery Was About  $2 \text{ Kw/Kg}$ . The Energy Density Of The Battery Was About  $100 \text{ Whkg}^{-1}$ . Both Electrode Materials Were Characterized By Their Ability To Operate At Increased Current Densities (Up To  $30 \text{ C}$ ) [44].

### 3.6. Lithium-Nickel Cobalt Aluminum Oxide (LiNiCoAlO<sub>2</sub>) Batteries.

In Commercial Li-Ion Batteries Layered Structural  $\text{LiCoO}_2$  Materials With A Theoretical Specific Capacity Of  $274 \text{ mahg}^{-1}$  Are The Primary Cathode. However, The Depletion And High Cost Of Cobalt Resources Severely Restrict Practical Applications Of  $\text{LiCoO}_2$  Materials [45].  $\text{LiNiO}_2$  Has Higher Theoretical Specific Capacity ( $275 \text{ mahg}^{-1}$ ) At Lower Cost and It Has Comparable Structure to  $\text{LiCoO}_2$  [46, 47]. However,  $\text{Ni}^{2+}$  Is Difficult To Completely Oxidize To  $\text{Ni}^{3+}$ , So It Is Still Impossible To Synthesize A Stoichiometric Ratio Of  $\text{LiNiO}_2$  By A Simple Process, Hence Limiting This Positive Electrode From Practical Applications. The Structural Order of the Nickel-Based Positive Electrode Material Significantly Enhanced By Incorporating Co [48]. The As Prepared  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  Material May Possess The Best Performance With The Molar Ratio Of Ni And Co Components  $8:2$  And The Degree Of Cation Mixing Is Less Than  $2\%$  [49]. However, Its Performance Is Greatly Affected By High

Temperature And Inevitably Affect The Stable Output Of Energy. With The Addition Of A Small Amount Of Al Stabilizes The Material Structure And Improves The Thermal Stability Of The Material. The  $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$  (NCA) Material Exhibits Brilliant Electrochemical Properties Obtained By Doping Co And Al Elements [50]. Among The Series of Materials with Different Ratios of Ni, Co, And Al Elements,  $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$  Is the Most Widely Researched Material and Has Attracted Full Interest

And Commercialization Due To Its Low Cost, Nontoxicity, and High-Energy Density. The First Company To Make Use Of NCA Cathode Materials To Power Cars Is Tesla, And This Made Significant Achievement In The Electric Vehicle Industry [51]. NCA Is A Promising Cathode Material Due To Its Admirable Structural Stability And High Capacity. However, The Cycle And Rate Performance Of NCA Materials Still Limit Its Large-Scale Application [52].

#### 4. GRAPHENE-BASED LI-ION BATTERIES:

At Present Li-Ion Batteries Are Dominating the Market for Portable Electronic Devices [53]. In Their Most Common Configuration, These Batteries Are Composed By An Intercalated Li Compound Cathode (For Example,  $\text{LiCoO}_2$  Or  $\text{LiFePO}_4$ ), A Graphitic Anode And An Organic Carbonate Electrolyte, With Achieved Energy Densities Of The Order Of  $120\text{--}150 \text{ Whkg}^{-1}$ . However, Li-Ion Do Not Meet Criteria Performances In Terms Of Cost, Energy Density, Charge/Discharge Rate, And Safety Needed To Enter In New Markets, Such As Those For All Evs And For The Storage Of Electrical Energy [54]. Graphene Has Opened New Possibilities In The Field Of Li-Ion Battery Materials Due To Its Light Weight, High Electrical Conductivity, Superior Mechanical Flexibility, And Chemical Stability [55] And Thanks To Its Large Surface To Mass Ratio Exceeding  $2600 \text{ m}^2\text{g}^{-1}$ , High Electrical Conductivity And High Mechanical Strength With The Added Value Of Mass Production [56] Is A Promising Material For Electrodes In Li-Ion Batteries [57]. These Properties Prove Advantageous When Graphene Is Used In The Anode. Graphene-Based Nanomaterials Have Been Revealed To Display Very Useful Properties For Both Energy Storage And Conversion. Today Li-Ion Batteries Are Been Used In A Wide Variety Of Peds. Energy And Power Density And Stability Under Cycles Of Charge And Discharge Are The Chief Performance Characteristics Of These Li-Ion Batteries [58]. The Performance Of The Batteries Is Linked To The Conductivity Of The Electrodes. Hence, To Improve the Electrochemical Properties of the Electrodes Through The Use Of Various Innovative Materials Great Interest and Research Effort

Have Been Spent [59]. Chief Among These Has Been The Use Of Carbon As An Additive [58]. Graphene A Material Can Achieve As A Superior Additive, Having A Crystalline Form That Is More Conductive Than, For Instance, Carbon Black [60]. The Anodic Material That Are Been Found To Be Suitable For Storing Lithium In Li-Ion Batteries Are Graphene Nanofilms, Graphene Paper, And Nanocomposites Of Graphene And Carbon Nanotubes [61]. Various Types Of Transition Metal Oxides, Including Those Of Tin, Nickel, Iron, And Copper, Have Been Combined With Graphene To Produce High-Performing Electrode Materials For Li-Ion Batteries [62]. The Reason Of Using Nanocomposites Instead Of Pure Graphene Sheets Is That The Secondary Material Prevents Aggregation And Loss Of Internal Surface Area When Multiple Layers Of Graphene Are Used [63]. Capacity In Batteries Can Reach Almost  $750 \text{ Mahg}^{-1}$  Using Hybrid Graphene Carbon Nanotube Anodes [63]. Those Hybrids Containing Tin Were Found To Have A Capacity As High As  $810 \text{ Mahg}^{-1}$  [64]. Research Efforts Have Also Been Made In Addressing The Diffusion Limits For Li-Ions In Electrode Materials [65].

##### 4.1. Graphene Composites as Cathode Materials for Li-Ion Batteries.

In Li-Ion Batteries, The Cathode Materials Play A Vital Role In Their Electrochemical Performance, Battery Capacity And More Than 30% Of The Cost Of The Entire Battery System. This Makes Very Important To Explore And Develop Cathode Materials Which Provides High Performance And Low Cost [66].  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  Is A Capable Candidate For Cathode Electrode Materials. It Shows Good Stability, High Energy Density, Enhanced Safety And Can Be Formed At Low Cost [67]. However, To Improve Its Electrochemical Performance,  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$ -Graphene Composites Are Prepared As Cathode Materials For Li-Ion Batteries Because Cation Disorder Occurs During Calcination And Results In Deterioration Of Its Kinetic Properties.  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  Graphene Composites Prepared By Mechanical Mixing Could Deliver A Capacity Of  $115 \text{ Mahg}^{-1}$  At 6C Reported By Jiang And Coworkers [68]. Rao *Et Al.*, Reported That  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$ -

Graphene Composites Prepared By Micro-Emulsion And Ball-Milling Route Could Deliver A Reversible Capacity Of 150 Mahg<sup>-1</sup> At 5C, Much Higher Than That Of Bare Lini1/3Mn1/3Co1/3O2 [69]. The Improved Performance Is Attributed To Grain Connectivity And High Electronic Conductivity.


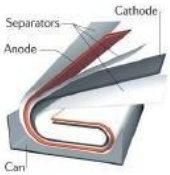
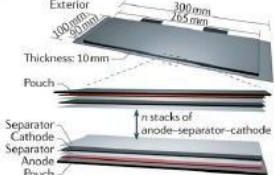
**4.2. Graphene Composites as Anode Materials for Li-Ion Battery.**

The Addition Of Graphene To Anode Materials Has Leads To Superior Electrical Conductivity, High Surface Area (2620 M2g<sup>-1</sup>), High Surface-To-Volume Ratio, Ultra-Thin Thickness Which Can Shorten The Diffusion Distance Of Ions, Structural Flexibility That Paves The Way For Constructing Flexible Electrodes, Thermal And Chemical Stability Which Guarantee Its Durability In Harsh Environments. At Present, Non-Carbon-Based Li-Ion Battery Anode Materials Are Mainly Tin-Based Electrode Materials, As Well As Silicon-Based And Transition Metal-Based Materials [70]. Even Though The Aforementioned Materials Have High Theoretical Capacity, Drawbacks To Their Use As Anode Materials Are Volume Expansion During Lithium/Delithiation And A Large Internal Stress. After Repeated Charging And Discharging, The Material Is Prone To Rupture, Resulting In Poor Cycling Performance. To Overcome These Disadvantages, Graphene Is Adopted.

**5. APPLICATIONS**

A Large Amount Of Carbon Dioxide Emission Produced By Petrol And Diesel Fuel Vehicles, Which Leads To Some Serious Consequences On Global Warming [71]. To Avoid Pollution Recently, The Government Of The UK, France, Germany, Netherlands And Other Countries Have Announced A Schedule To Stop Producing Petrol Vehicles, Most Of Which Are From 2025 To 2040 Respectively [72]. Projections Estimate That Worldwide, More Than 125 Million Evs Will Be On The Road by 2030. At The Heart Of These Advanced Vehicles Is The Li-Ion Battery Which Provides The Required Energy Storage [73]. As Energy Shortage and Environmental Problems Emerge As the Great Challenges, the Development of Electric Drive Vehicles Such As Hevs, Evs Instead Of Cars Driven By Internal

Combustion Engines (Ices) Has Received A Great Deal of Attention Worldwide [73, 74]. As A Key Component, Battery Plays Very Important Role In Developing EV And HEV. In Various Batteries, Rechargeable Li-Ion Batteries Become More And More Important As The Power Sources In The Evs Application [75]. Individual Cell Design Can Come In Several Different Forms And Shapes That Can Be Seen In Table 1 [76]. This Flexibility Helps To Broaden The Uses For Li-Ion Batteries As They Can Be Designed Around Multiple Different Form Factors For Each Specific Need [76].

Shape	Cylindrical	Prismatic	Pouch
Diagram			
Electrode Arrangement	Wound	Wound	Stacked
Mechanical Strength	++	+	-
Heat Management	-	+	+
Specific Energy	+	+	++
Energy Density	+	++	+

Comparisons of Different Types of Li-Ion Batteries Used In Evs

**5.1. Li-Ion Batteries in Portable Electronic Devices (PED):**

The Most Commonly Used Rechargeable Batteries Nowadays Is Li-Ion Batteries. Since 1991 When The Sony Corporation Commercialized The First Li-Ion Battery, The Li-Ion Batteries Bring Peds To A New Age. Li-Ion Batteries Is The Best Energy Storage Option For Small-Sized Peds, Such As Mobile Phones, Laptops, Digital Cameras, And Others Due To Their Advent Has Been Very Challenging To Other Types Of Batteries, Which Could Be Ascribed To A Number Of Advantages, Such As High Specific Energy (Typically Twice That Of Standard Ni-Cd Batteries), Low Self-Discharge Rate, High Voltage Of About 3.6

V (Three Times That Of Typical Ni-Based Battery), Maintenance Free, Lightweight, Good Safety, And Excellent Cycling Performance. Development of Li-Ion Batteries Can Be Found In Several

Excellent Reviews [77, 78]. It Should Be Mentioned That Because Of Their Thin And Customizable Shape, Li-Ion Polymer Batteries Are Very Attractive For Peds, Especially For Ultra-Slim Laptops, Mobile Phones, Tablets, And Wearable Electronic Devices. When Polymer Electrolytes Replace Liquid Electrolytes, The Resulting Batteries Are Called Li-Ion Polymer Batteries. With The Introduction Of New Materials And Technologies, Li-Ion Batteries Continuously Improve Their Energy Density, Power Density, Lifespan, And Safety [79]. Although The Price Is Getting Lower Year-By-Year, Li-Ion Batteries Still Cost More Than Other Competing Batteries. Further, To Ensure Safe Operation Li-Ion Batteries Needs Additional Protection Circuits To Limit Voltages And Currents And Also Li-Ion Batteries Would Lose Their Capacity And Life Cycle When Are Stored In Temperatures Over 30C For An Extended Period. Nowadays, Battery Scientists And Engineers Are Making Significant Efforts To Address The Drawbacks Of Li-Ion Batteries [80].

### 5.2. Li-Ion Batteries in Electric Train:

Today, Li-Ion Battery Technology Has Become Very Popular Among Electric Vehicle Manufacturers. It Has Replaced Ni-MH And Ni-Cd Technologies Due To Its High Energy Density, High Cell Voltage, Long Shelf And Cycle Life With No Memory Effect And Environmental Issues With Both Ni-Cd And Ni-MH Technologies. While Its Costs Are Still High, Manufacturing Process Improvements And Economies Of Scales Are Helping Reducing Costs Significantly [81]. In 2014, East Japan Railway Company Developed A Battery Train Equipped With Li-Ion Batteries; The Main Objective Is To Run The Train In Catenary-Free Region, The Train Is Equipped With 190 Kwh Batteries And Can Go Up To 100 Km<sup>-1</sup> And Run Approximately 20 Km In Catenary-Free Operation [82]. Both High Energy Capacity And High Power Output Batteries Are Required Since The Weight Of The Vehicle And The Longer Distance That The Vehicle Needs To Run In Catenary-Free Mode. Energy-Efficient Catenary-Free Operation of Electric Multiple Units with Li-Ion Batteries Differs From the Case Where

A Super Capacitor Or An Electric Double-Layered Capacitor EDLC Is Used, As The Dynamic Behavior Of Capacitors Is Different From Li-Ion Batteries [83].



**Figure.1** Series BEC819 Battery-Powered Train Charged From AC Overhead Line. High-Capacity Li-Ion Batteries (About 360 Kwh Output) Are Installed Under The Floor Of The Train.



Recently For Installing High-Capacity Li-Ion Batteries In Rolling Stock And Using Them For Traction Power, Improvement Is Being Made. When Compare To Conventional Diesel Railcars Use Of Batteries In Rolling Stock That Runs On Non-Electrified Sections Of Track Can Save Energy, Minimize Noise, And Reduce Maintenance Requirements. Using Energy Stored In Batteries That Are Charged From The Alternating Current Overhead Lines Hitachi Has Productively Commercialized A Battery-Powered Train That Can Run On Non-Electrified Sections Of Track. The Hybrid Rolling Stock Have Been Delivered As The JR East Series HB-E210 And Series HB-E300 Trains (Fleet Expansion Trains). Types Of Li- Ion Batteries Can Be Selected To Create The Optimum System For The Application Are. (1) High Output- Density Battery Module Developed For Hybrid Vehicles, This Battery Module Features A Thin And

Compact Modular Design Created For Onboard Use. Each Hybrid Train Has Been Equipped With 16 Of These Battery Modules To Absorb Regenerative Power.

(2) High Energy-Density Battery Module Developed For Industrial Use, This Battery Module Provides High Storage Capacity While Ensuring Constant Charge/Discharge Output Performance. The Train Has Been Equipped With 216 Of These Battery Modules To Ensure Stable Travel Distances.

## REFERENCES

1. B. Xu, D. Qian, Z. Wang, Y. S. Meng, *Materials Science and Engineering R*, 73 (2012) 51.
2. J.M. Tarascon, M. Armand, *Nature*, 414 (2001) 359.
3. B. Dunn, H. Kamath, J. M. Tarascon, *Science*, 334 (2011) 928.
4. J. B. Goodenough, K. S. Park, *J. Am. Chem. Soc.*, 135 (2013) 1167.
5. D. Larcher, J. M. Tarascon, *Nat. Chem.*, 7 (2015) 19.
6. B. V. Ratnakumar, M. C. Smart, A. Kindler, H. Frank, R. Ewell, S. Surampudi, *J. Power Sources*, (2003) 906.
7. M. Arbabzadeh, J. X. Johnson, G. A. Keoleian, P. G. Rasmussen And L. T. Thompson, *Environ. Sci. Technol.*, 50 (2016) 1046.
8. M. A. Pellow, C. J. M. Emmott, C. J. Barnhart, S. M. Benson, *Energy Environ. Sci.*, 8 (2015) 1938.
9. A. Bilich, K. Langham, R. Geyer, L. Goyal, J. Hansen, A. Krishnan, J. Bergesen, P. Sinha, *Environ. Sci. Technol.*, 51(2017) 1043.
10. R. J. Huang Et Al. *Nature*, 514 (2014) 218.
11. S. Pacala, R. Socolow, *Science*, 305 (2004) 968.
12. T. Kim, W. Song, D. Y. Son, L. K. Ono, Y. Qi. *J. Mater. Chem. A*, 7 (2019) 2942.
13. P. G. Bruce, B. Scrosati, J. M. Tarascon, *Angew. Chem., Int. Ed.*, 47 (2008) 2930.
14. C. Liu, F. Li, L. P. Ma, H. M. Cheng, *Adv. Mater.*, 22 (2010) E28.
15. M. V. Reddy, G. V. S. Rao, B. V. R. Chowdari, *Chem. Rev.*, 113 (2013) 5364.
16. T. Stephenson, Z. Li, B. Olsen, D. Mitlin, *Energy Environ. Sci.*, 7 (2014) 209.
17. O. Shimamura, T. Abe, K. Watanabe, Y. Ohsawa, H. Horie, *World Electr. Veh. J.*, 1 (2007).
18. K. M. Abraham, Z. Jiang, *J. Electrochem. Soc.*, 143 (1996) 1.
19. P. G. Bruce, S. A. Freunberger, L. J. Hardwick, J. M. Tarascon, *Nat. Mater.*, 11 (2012).
20. Z. Peng, S. A. Freunberger, Y. Chen, P. G. Bruce, *Science*, 337 (2012) 563.
21. G. Girishkumar, B. Mccloskey, A. C. Luntz, S. Swanson, W. Wilcke, *J. Phys. Chem. Lett.*, 1 (2010) 2193.
22. T. Ogasawara, A. D'Ebart, M. Holzappel, P. Nov' Ak And P. G. Bruce, *J. Am. Chem. Soc.*, 128 (2006) 1390.
23. Y. Shao, F. Ding, J. Xiao, J. Zhang, W. Xu, S. Park, J. G. Zhang, Y. Wang And J. Liu, *Adv. Funct. Mater.*, 23 (2013) 987.
24. K. Takechi, T. Shiga, T. Asaoka, *Chem. Commun.*, 47 (2011) 3463.
25. H. K. Lim, H. D. Lim, K. Y. Park, D. H. Seo, H. Gwon, J. Hong, W. A. Goddard, H. Kim, K. Kang, *J. Am. Chem. Soc.*, 135 (2013) 9733.
26. Y. Liu, R. Wang, Y. Lyu, H. Li, L. Chen, *Energy Environ. Sci.*, 7 (2014) 677.
27. Y. Qiao, J. Yi, S. Wu, Y. Liu, S. Yang, P. He, H. Zhou, *Joule*, 1 (2017) 359.
28. S. Xu, S. K. Das, L. A. Archer, *RSC Adv.*, 3 (2013) 6656.
29. S. Yang, Y. Qiao, P. He, Y. Liu, Z. Cheng, J. Zhu H. Zhou, *Energy Environ. Sci.*, 10 (2017) 972.
30. R. Strobel, S. E. Pratsinis, *Platinum Metals Rev.*, 53 (2009) 11.
31. R. Strobel, A. Baiker, S. E. Pratsinis, *Adv. Powder Technol.*, 17 (2006) 457.
32. T. Xia, M. Kovoichich, M. Liong, L. Mädler, B. Gilbert, H. Shi, *ACS Nano*, 2(2008) 2121.
33. L. Mädler, T. Sahm, A. Gurlo, J. D. Grunwaldt, N. Barsan, U. Weimar, *J. Nanoparticle Res.*, 8 (2006) 783.
34. T. Patey, R. Büchel, M. Nakayama, P. Novak, *Phys. Chem. Chem. Phys.*, 11 (2009) 3756.
35. S. H. Ng, T. J. Patey, R. Büchel, F. Krumeich, J. Z. Wang, H. K. Liu, *Phys. Chem. Chem. Phys.*, 11 (2009) 3748.

36. H. Mohammadi, M. Khosravi, S. M. Jafari, *Anal. Bioanal. Electrochem*, 10 (2018) 1.
37. H. Wang, N. Mao, J. Shi, Q. Wang, W. Yu, X. Wang, *Appl. Mater. Interfaces*, 7 (2015) 2882.
38. T. F. Yi, P. P. Peng, X. Han, Y. R. Zhu, S. Luo, *Solid State Ionics*, 329 (2019) 131.
39. Ellis, B. L. Et Al, *Chem. Mater*, 22 (2010) 691.
40. Song, H. K. Et Al, *Adv. Funct. Mater*, 20 (2010) 3818.
41. C. Ling, R. Zhang, *Front. Energy Res*, 5 (2017) 30.
42. R. R. Zhao, G. Z. Ma, L. C. Zhu, A. J. Li, H. Y. Chen, *Int. J. Electrochem. Sci*, 7 (2012) 10923.
43. A. A. Chekannikov, R. R. Kapaev, S. A. Novikova, T.L.Kulova<sup>1</sup>, A. M. Skundin<sup>1</sup>, A. B. Yaroslavtsev, *Int. J. Electrochem. Sci*, 11 (2016) 2219.
44. A. A. Chekannikov, A. A. Kuz'mina, T. L. Kulova, S. A. Novikova, A. M. Skundin, I. A. Stenina, A. B. Yaroslavtsev, *Proceedings Of The Scientific-Practical Conference "Research And Development"*, (2016) 341.
45. T. F. Yi, P. P. Peng, X. Han, Y. R. Zhu, S. Luo, *Solid State Ionics*, 329 (2019) 13.
46. T. Ohzuku, A. Ueda, M. Nagayama, Y. Iwakoshi, and H. Komori, *Electrochim. Acta*, 38 (1993) 115.
47. T. Ohzuku, A. Ueda, and M. Nagayama, *J. Electrochem. Soc*, 140 (1993) 1862.
48. M. S. Whittingham, *Chem. Rev*, 114 (2014) 11414.
49. S. Xia, F. Li, F. Cheng Et Al, *J. Electrochem. Soc*, 165 (2018) A1019.
50. J. Duan, P. Dong, D. Wang Et Al, *J. Alloys Compd*, 739 (2018) 335.
51. K. J. Park, J. Y. Hwang, H. H. Ryu Et Al, *ACS Energy Lett*, 4 (2019) 1394 .
52. J. Y. Liao, A. Manthiram, *J. Power Sources*, 282 (2015) 429.
53. J. B. Goodenough, K. S. Park, *J. Am. Chem. Soc*, 135 (2013)1167.
54. M. Armand, J. M. Tarascon, *Nature*, 451 (2008) 652.
55. C. Su, X. Bu, L. Xu, J. Liu, C. Zhang, *Electrochim Acta*, 64 (2012) 190.
56. F. Bonaccorso, A. Lombardo, T. Hasan, Z. Sun, L. Colombo, A. C. Ferrari, *Mater.Today*, 15 (2012) 564.
57. F. Bonaccorso, L. Colombo, G. Yu, M. Stoller, V. Tozzini, A. C. Ferrari, R. S. Ruoff, V. Pellegrini, *Science*, (2014).
58. M. Liang, L. J. Zhi, *Mater Chem*, 19 (2009) 5871.
59. P. G. Bruce, B. Scrosati, J. M. Tarascon, *Angew Chem Int Ed*, 47 (2008) 2930.
60. D. R. Cooper, B. D. Anjou, N. Ghattamaneni, B. Harack, M. Hilke, A. Horth, Et Al., *ISRN Condens Matter Phys*, (2012) 501686.
61. G. Kucinskis, G. Bajars, J. Kleperis, *J Power Sources*, 240 (2013) 66e79.
62. S. L. Chou, J. Z. Wang, M. Choucair, H. K. Liu, J. A. Stride, S. X. Dou, *Electrochem Commun*, 12 (2010) 303.
63. E. Yoo, J. Kim, E. Hosono, H. Zhou, T. Kudo, I. Honma, *Nano Lett*, 8 (2008) 2277.
64. S. M. Paek, E. J. Yoo, I. Honma, *Nano Lett*, 9 (2009) 72.
65. V. Subramanian, H. W. Zhu, B. Q. Wei, *J Phys Chem B*, (2006) 110.
66. N. Nitta, F. Wu, J. T. Lee, and G. Yushin, *Materials Today*, 18 (2015) 252.
67. J. P. Zhu, Q. B. Xu, J. J. Zhao, G. Yang, *J Nanosci Nanotechnol*, 12 (2012) 2534.
68. K. C. Jiang, S. Xin, J. S. Lee, J. Kim, X. L. Xiao, Y. G. Guo, *Phys Chem Chem Phys*, 14 (2012) 2934.
69. C. V. Rao, A. L. M. Reddy, Y. Ishikawa, P. M. Ajayan, *Appl Mater Interfaces*, 3 (2011) 2966.
70. X. Zhu, Y. Zhu, S. Murali, M. D. Stoller, R. S. Ruoff, *J Power Sources*, 196 (2011) 6473.
71. R. J. Huang Et Al, *Nature* 514 (2104) 218.
72. F. W. Geels, *Energy Res. Soc. Sci*, 34 (2017) 224.
73. H. Yu, H. Kim, Y. Wang, P. He, D. Asakura, Y. Nakamura, H. Zhou, *Phys. Chem. Chem. Phys*, 14 (2012) 6584.
74. M. M. Thackeray, C. Wolverton, E. D. Isaacs, *Energy Environ. Sci*, 5 (2012) 7854.
75. A. Manthiram, *J. Phys. Chem. Lett*, 2 (2011) 176.
76. T. Horiba, *IEEE*, 102 (2014) 939.
77. J. B. Goodenough, *Nat. Electron*, 1 (2018) 204.
78. G. E. Blomgren, *J. Electrochem. Soc*, 164 (2017) 5019.
79. Y. Liang, W. Zhang, D. Wu, Q. Q. Ni, M. Q. Zhang, *Adv. Mater. Interfaces*, 5 (2018) 1800430.
80. Y. Liang, C. Z. Zhao, H. Yuan, Y. Chen, W. Zhang, J. Q. Huang<sup>4</sup>, D. Yu, Y. Liu, M. M. Titirici, Y. L. Chueh, H. Yu, Q. Zhang, *Infomat*, 1 (2019) 6.
81. R. A. Meyers, Springer, ( 2012)
82. H. Hirose, K. Yoshida, K. Shibamura, *IEEE*, (2012) 1.
83. N. Ghaviha, J. Campillo, M. Bohlin, E. Dahlquist, *Mod. Transport*, 27(3) (2019) 153.